

**Motivation:** Among the great Mars mineral problems are the predictions of both carbonates and clays as alteration products and the lack of observational evidence to support those predictions. In spite of geochemical evidence of sulfur and chlorine in the soils, assignment of specific sulfates and chlorides has remained elusive. The purpose of this contribution is to show several common alteration minerals that are consistent with the short-wave infrared surface spectra and geochemistry, briefly consider the silicate problem, propose an additional method of soil formation and review what surface measurements in the spectral range from approximately 1 to 4  $\mu\text{m}$  can do to help resolve remaining ambiguities of surface mineralogy.

**Background:** It is widely held that the SNC meteorites come from Mars and thereby study of these meteorites can tell us a great deal about the planet [e.g. 1]. However, typical SNC spectra are dominated by their basaltic lithologies [2,3] which is in marked contrast to the measured spectra of the planet (Figure 1) [e.g. 4]. Weak features of unaltered mafics have been observed [e.g. 5]. However, all remote spectra contain contributions from the surface, atmospheric gasses and dust and interpretation of spectral variation on Mars needs to account for materials on the ground and in the sky.

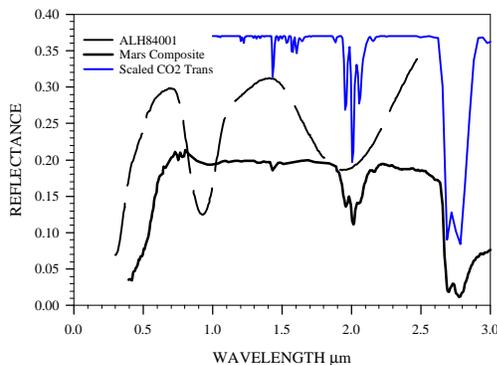


Figure 1: ALH84001 [3], composite Mars dark [4], Calculated CO<sub>2</sub> atmosphere [6].

Alteration minerals are found in SNCs but they are trace constituents. Alteration products include carbonates, sulfates, and clays. Clay minerals are typically Fe-rich smectites or Al-rich illites, or “iddingsite” a fine-grained mixture of Fe smectites and ferric oxy-hydroxides [e.g. 7]. Martian soil composition is similar at the Viking and Pathfinder sites [8] with en-

hanced sulfur and chlorine, high iron and silicates. Geochemical modeling of soil compositions and of gas-rock interactions predict quartz, carbonates, clays (smectites), ferric oxides and oxyhydroxides and sulfates [e.g. 9,10]. In both SNCs and soil models, the dominant alteration products, carbonates and clays, are only equivocally identified in spectral observations of the planet.

**NIR/SWIR Spectra: Sulfates and Halides.** It is often assumed that evaporite salts and halides are incompatible with the short-wave infrared (SWIR) spectra of Mars due to abundant absorptions and overtones due to structural water [e.g. 11]. However, Figure 2 shows that some common alteration minerals are compatible with SWIR spectra including the anhydrous sulfates thenardite and anhydrite and halite (NaCl). These minerals in particular are characterized by at most weak features at 1.4 and 1.9  $\mu\text{m}$  from adsorbed water. As shown by Bishop and Pieters [12] for montmorillonites, at low temperature and under Martian atmospheric pressures, we might expect adsorbed water to come off, reducing these features in strength. Such weakly hydrated surface minerals are consistent both with the Viking measurement of a few % water and with recent modeling of the strength of the 3- $\mu\text{m}$  absorption feature [13]. Figure 2 demonstrates that minerals with weak 1.4 and 1.9  $\mu\text{m}$  features retain strong 3- $\mu\text{m}$  bands. These minerals are otherwise bright and featureless so in spectra of mixed mineralogies they will take on the character of pigmenting Fe-oxides and oxyhydroxides as observed in the visible. Spectra from the ISM instrument on Phobos-2 suggest the presence of an absorption feature at 1.75  $\mu\text{m}$  in bright regions [14, Fig. 2] which would be consistent with gypsum. The spectral behavior of both hydrous and anhydrous sulfates under low temperature and pressure conditions needs to be explored.

**Silicates: Zeolites, Feldspars and Clays.** Similar to the sulfates and halides, zeolites typically exhibit pronounced features associated with structural water [e.g. 15]; however the mineral sodalite is similar to its anhydrous salt cousins and shows only 1.4 and 1.9  $\mu\text{m}$  absorptions (Fig. 2). Under low temperature and atmospheric pressure conditions it is also expected to be consistent with Mars spectra when part of a mineral mixture. Many feldspars are also spectrally neutral at the SWIR wavelengths.

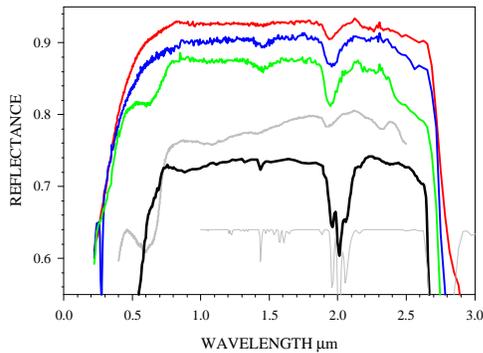


Figure 2: Spectra from top: Thenardite, Halite, Anhydrite, Sodalite, [16,17] Composite Bright Mars [4], and CO<sub>2</sub> atmosphere [6]. Spectra scaled and/or offset for clarity.

Clay minerals remain problematic. Bishop and Pieters [12] have shown that even under dehydrating conditions the typical clay features near 2.2- 2.3  $\mu\text{m}$  do not disappear and often are enhanced as structural water is no longer depressing the continuum level. Erard and Calvin [4] suggested that the shape of the 3- $\mu\text{m}$  feature is consistent with some clays but the uniqueness of the band shape is a concern. The 2.2-2.3  $\mu\text{m}$  band could disappear in poorly crystalline or dehydroxylated clays [18] and it has been suggested that acid weathering by volcanic aerosols has suppressed the maturation of martian soils inhibiting the presence of any strongly crystalline components [19]. One possible solution is that the features of typical clay minerals are not observed because they are not present in the martian soil.

**Fumerole model:** A potential “real-life” model of gas-solid interactions on Mars is provided by volcanic fumeroles and their encrustations and sublimate deposits. Mars has had extensive volcanism in the past and vents at which volcanic gasses escaped are expected to occur. Terrestrial fumerole deposits exhibit a few common minerals and amorphous products can dominate. The most common minerals are sulfates and Fe-oxides. Silicates are amorphous or quartz polymorphs which form clays only after secondary alteration and exposure to air. Some fumeroles deposit magnetite and Fe sulfides [20-23]. Stoiber and Rose [20] note that the most common fumerole minerals are sulfur, hematite, halite, sylvite, gypsum, anhydrite, and thenardite. We note with interest that all of these minerals are compatible with Mars spectra. If a portion of the martian soil was derived from fumerole deposits and subsequently redistributed through aeolian processes it might explain the lack of observed carbonates as well as local variations in sulfur content due to source magma variations. This model can also help explain models which suggest that the Martian soil composition can not be directly linked to that of the rocks at the Pathfinder site [24]. Fumerole minerals in the soil could be further altered by atmosphere-surface interactions or by upwardly migrating ground water. Bishop [25, this conference] has recently considered the role of both palagonitization and vent alteration.

**Surface SWIR spectra:** A number of features of the Martian SWIR spectrum could be resolved through in-situ measurements which can make direct observations of the atmosphere and resolve mineralogic ambiguities. In particular the contribution of atmospheric dust observed absorption features could be constrained. As has been shown with Pathfinder [26] the Martian sky radiance imparts a definite color and also exhibits absorption features attributed to the dust mineralogy. The spectrum of Mars has a weak feature from 2.3 to 2.4  $\mu\text{m}$  which contains contributions from atmospheric CO and minerals [e.g. 27,28]. Clear separation of the gas and mineralogic contributions has not yet been achieved. In addition hydrated minerals are expected to have at least weak contributions at 1.4 and 1.9  $\mu\text{m}$ , consistent with the 3- $\mu\text{m}$  band. Surface SWIR observations at sufficient spectral resolution will allow the deconvolution of the 2.0  $\mu\text{m}$  envelope, resolving the contribution of atmospheric CO<sub>2</sub> and the amount of H<sub>2</sub>O in minerals. Recently, features have been identified near 3.4  $\mu\text{m}$  [29]. High spectral resolution observations can help determine the origin of these features.

**References:** [1]McSween, *Meteoritics*, **29**, 757, 1994. [2]Sunshine et al., *Icarus*, **105**, 79, 1993. [3] Bishop et al., *Meteorit. Planet. Sci.*, **33**, 699, 1998. [4]Erard and Calvin, *Icarus*, **130**, 449, 1997. [5]Mustard and Sunshine, *Science*, **267**, 1623, 1995. [6]Crisp, *JGR*, **95**, 14577, 1990. [7] Gooding, *Icarus*, **99**, 28, 1992. [8]Rieder et al., *Science*, 278, 1771, 1997. [9]Banin et al., in *Mars*, 594, 1992. [10]Gooding, et al., in *Mars*, 626, 1992. [11]Crowley, *JGR*, **96**, 16231, 1991. [12]Bishop and Pieters, *JGR*, **100**, 5369, 1995. [13]Yen et al., *JGR*, **103**, 11125, 1998. [14]Erard et al., *Icarus*, **111**, 317, 1994. [15]Clark et al., *JGR*, 95, 12653, 1990. [16]Clark et al., USGS Spectral Library, <http://spec-lab.cr.usgs.gov>. [17]Hook and Tan, ASTER Spectral Library, <http://speclib.jpl.nasa.gov>. [18]Burns, *GCA*, **57**, 4555, 1993. [19]Banin et al., *JGR*, **102**, 13341, 1997. [20]Stoiber and Rose, *GCA*, **38**, 495, 1974. [21]Naughton, et al., *J. Volcanol. Geotherm. Res.*, **1**, 149, 1976. [22]Keith, *J. Volcanol. Geotherm. Res.*, **45**, 227, 1991. [23]Getahun et al., *J. Volcanol. Geotherm. Res.*, **71**, 73, 1996. [24]Brueckner et al., *LPSC XXX*, #1250, 1999. [25]Bishop et al., *JGR*, **103**, 31457, 1998. *LPSC XXX*, #1887, 1999. [26]Thomas et al., *JGR*, **104**, 8795, 1999. [27]Clark, et al., *JGR*, **95**, 14463, 1990. [28]Encrenaz and Lellouch, *JGR*, **95**, 14589, 1990. [29]Cloutis and Bell, *LPSC XXX*, #1945, 1999.